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Algorithms for Radio Networks

Geometric Routing

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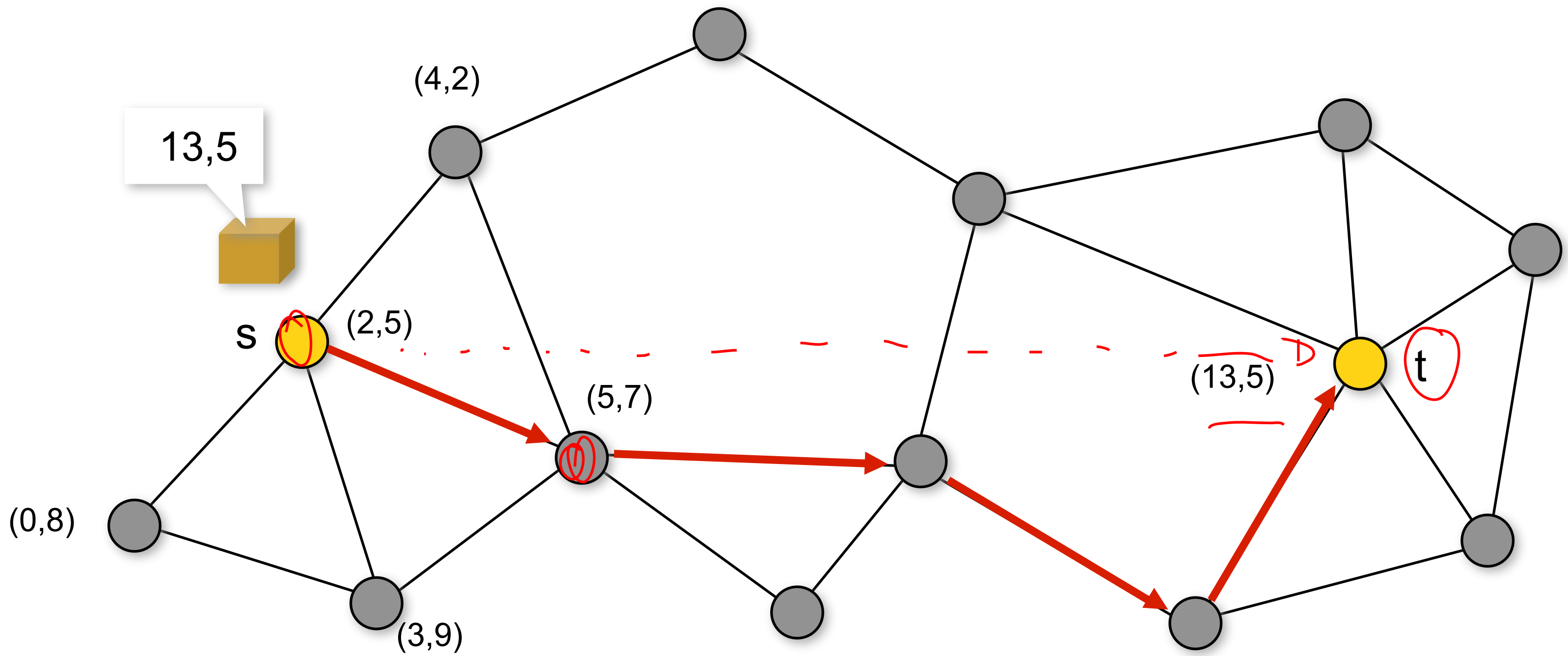
IIF

Geometric Routing

- **Routing target:**
  - geometric position
- **Idea**
  - send message to the neighbor closest to the target node (greedy strategy)

- **Advantagements**
  - only local decisions
  - no routing tables
  - scalable

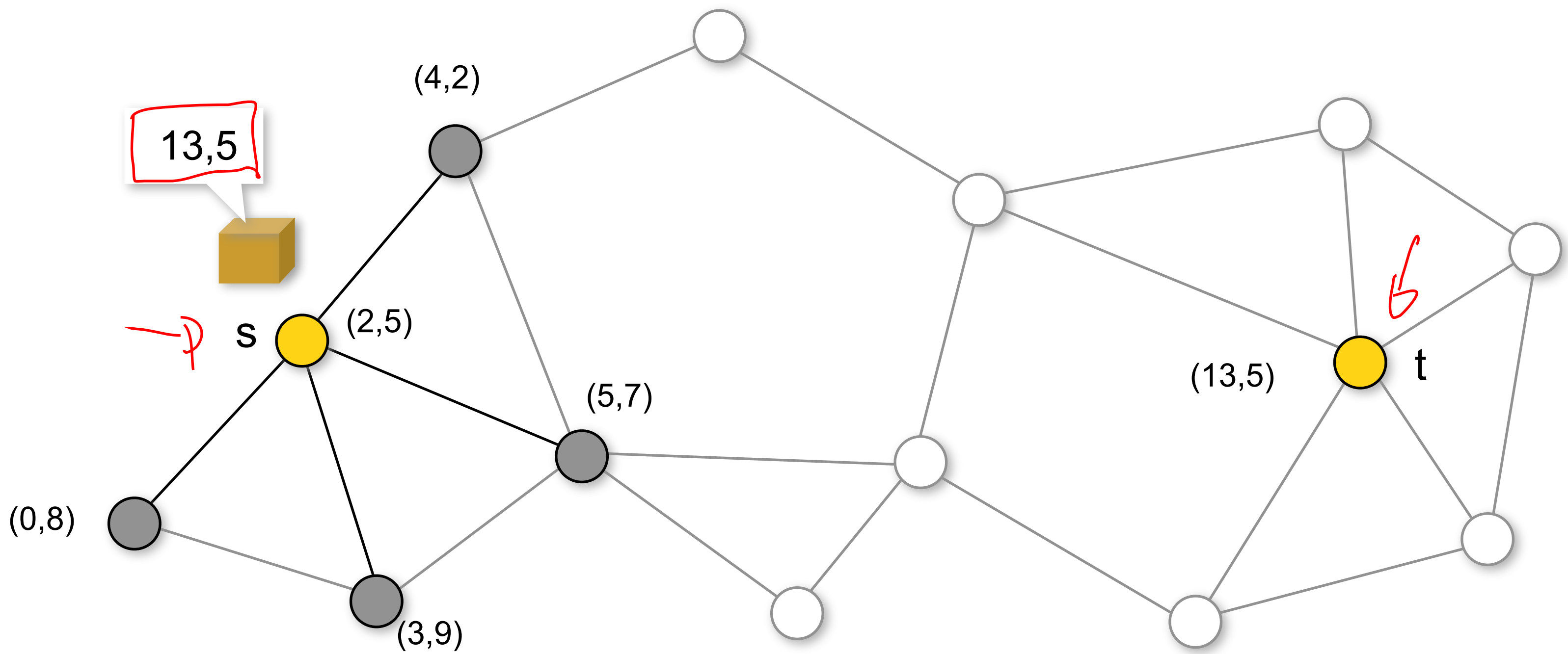


Position Based Routing

- **Prerequisites**
  - Each node knows its position (e.g. GPS)
  - Positions of neighbors are known (beacon messages)
  - Target position is known (location service)

outdoor

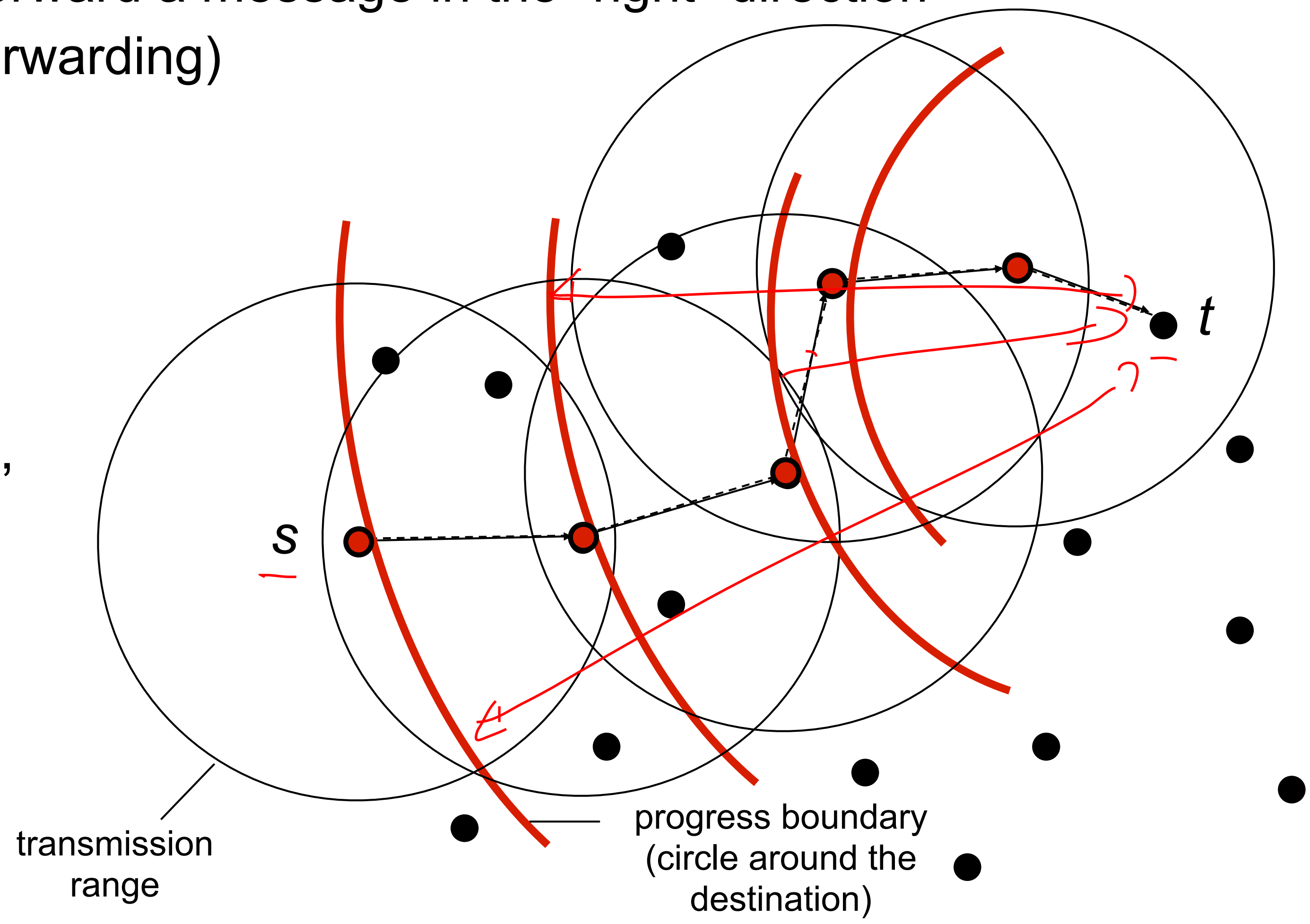
Zebra-Net



Greedy forwarding and recovery

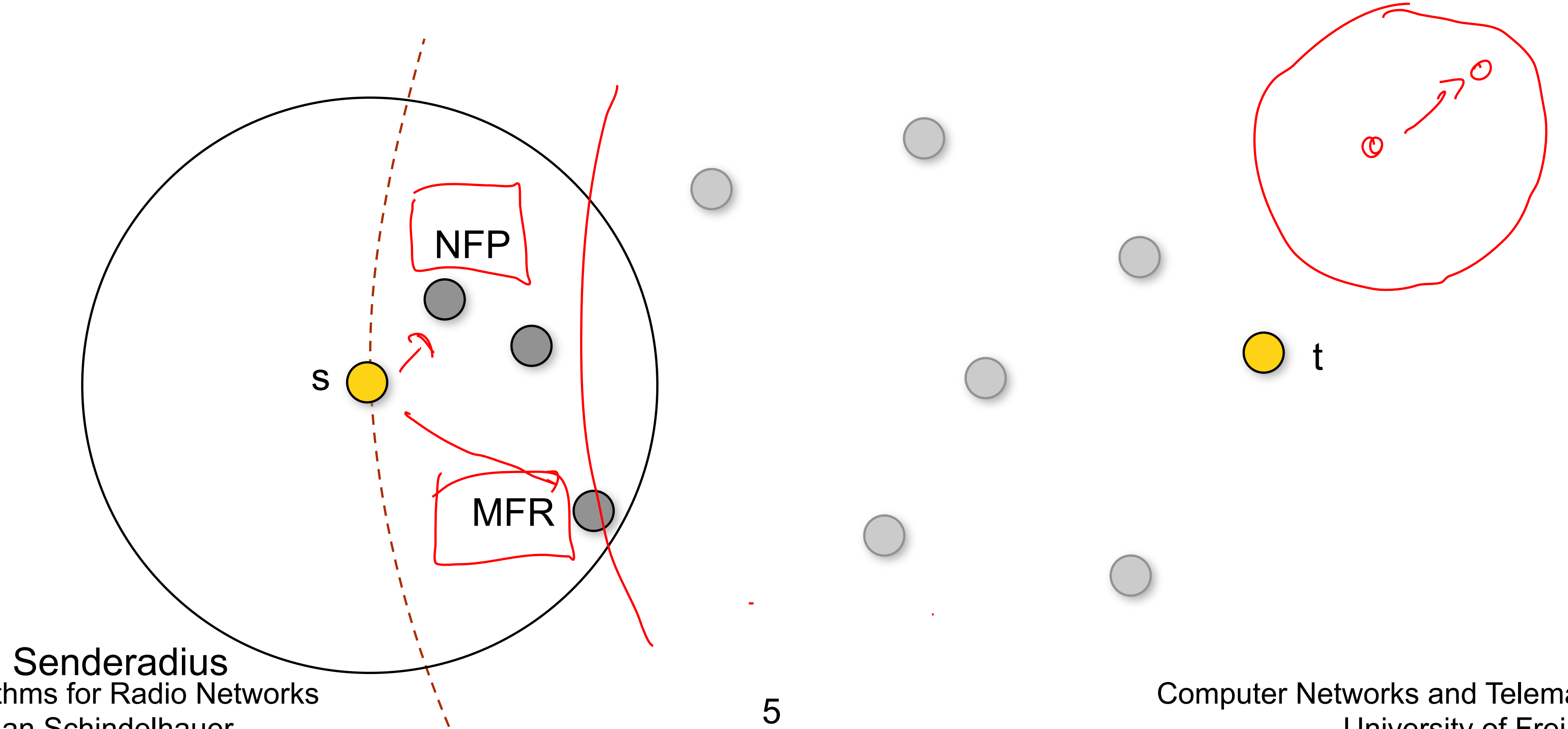
- **With position information**
  - one can forward a message in the "right" direction (greedy forwarding)

no routing tables, no flooding!



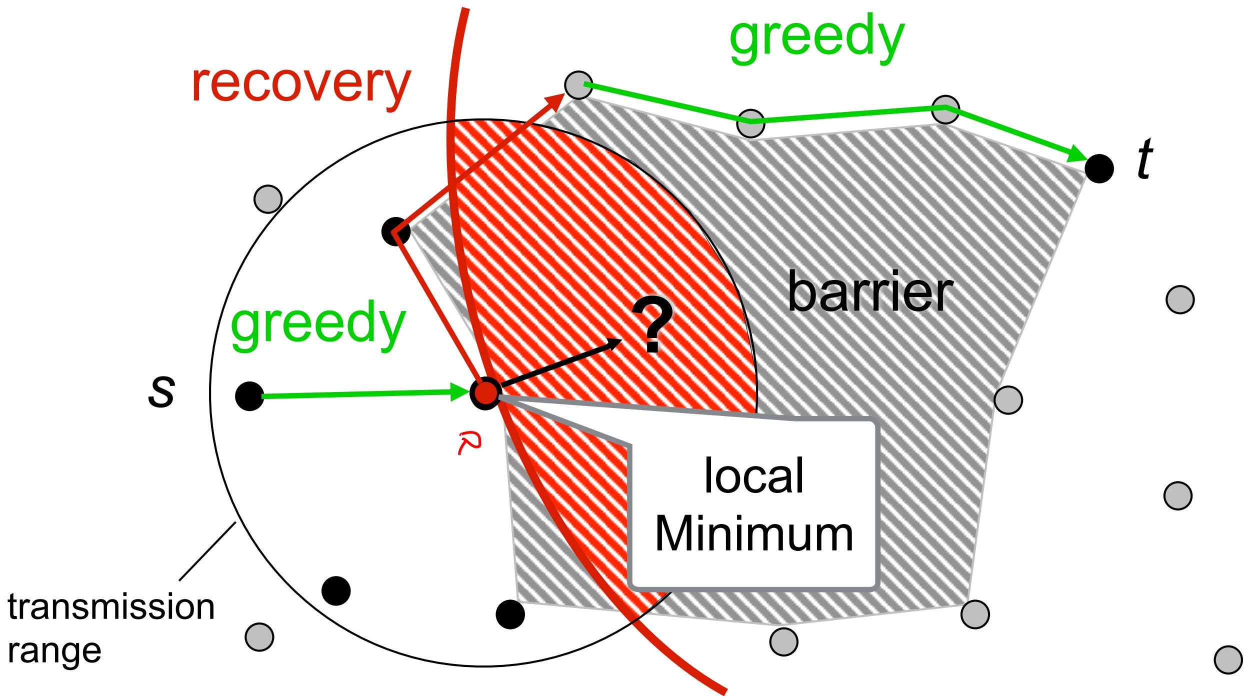
First Approaches

- **Routing in packet radio networks**
- **Greedy strategies:**
  - MFR: Most Forwarding within Radius [Takagi, Kleinrock 1984]
  - NFP: Nearest with Forwarding Progress [Hou, Li 1986]



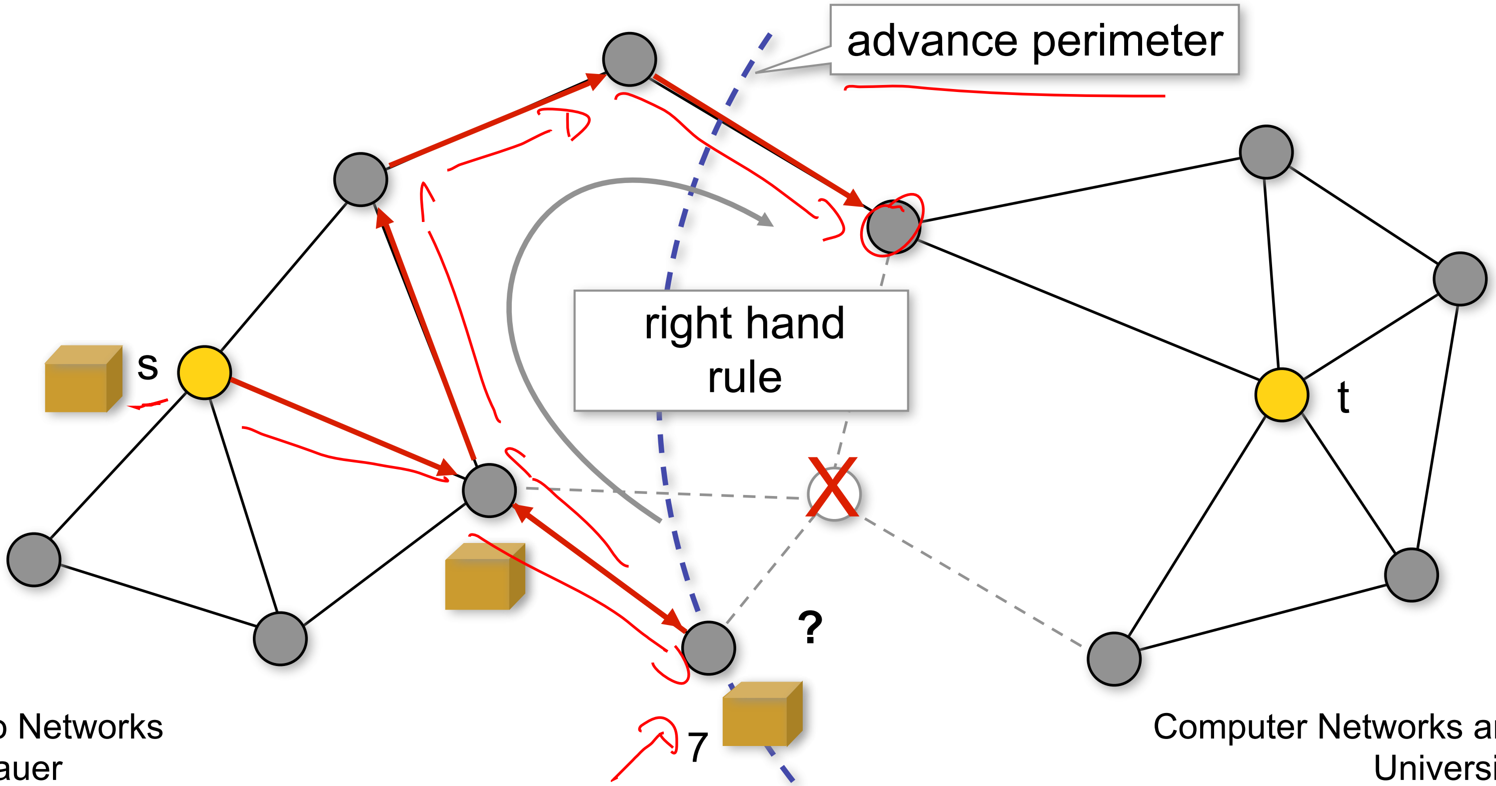
Greedy forwarding and recovery

- **Greedy forwarding is stopped by barriers**
  - (local minima)
- **Recovery strategy:**
  - Traverse the border of a barrier until a forwarding progress is possible (right-hand rule)
  - routing time depends on the size of barriers



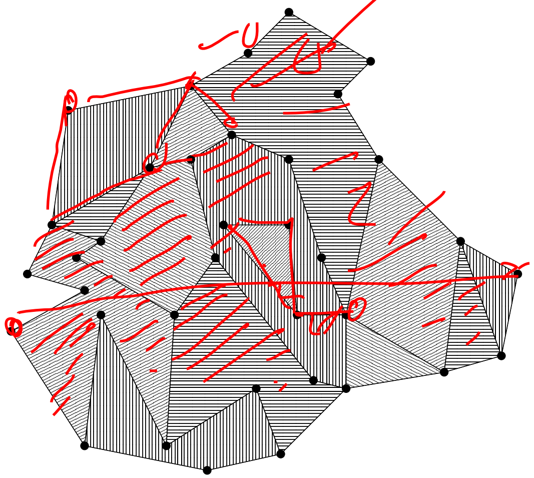
Position Based Routing

- **Combination of greedy routing and recovery strategy**
- **Recovery from local minima (right hand rule)**
    - Example: GPSR [Karp, Kung 2000]



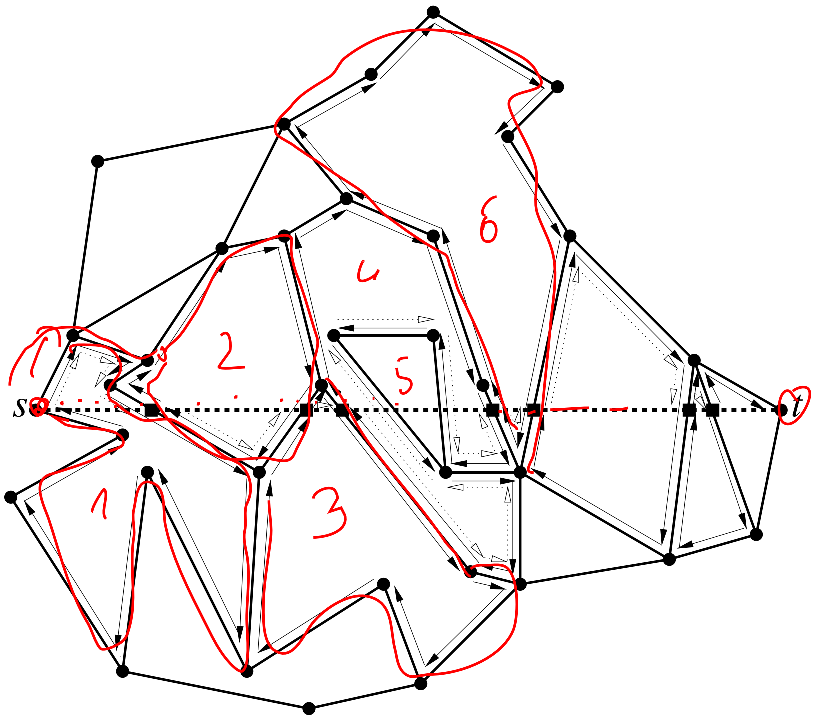
Problems of Recovery

face



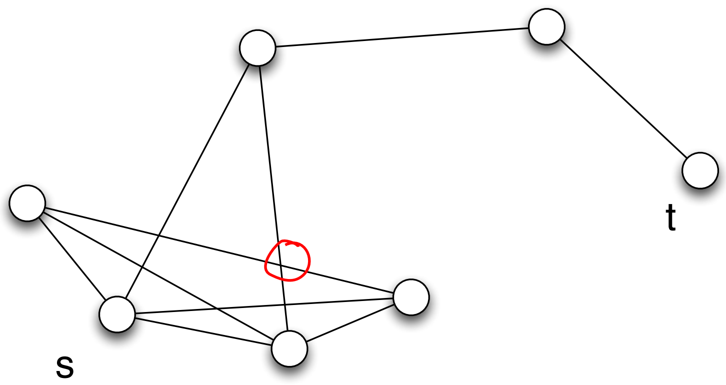
- **Recovery strategy can produce large detours**
- **Solutions**
  - Follow recovery strategy until the situation has absolutely improved
    - e.g. until the target is closer
  - Follow a thread
    - e.g. Face Routing strategy
    - by Kuhn, Wattenhover, Zollinger, Asymptotically Optimal Geometric Mobile Ad-Hoc Routing, DIAL-M 2002

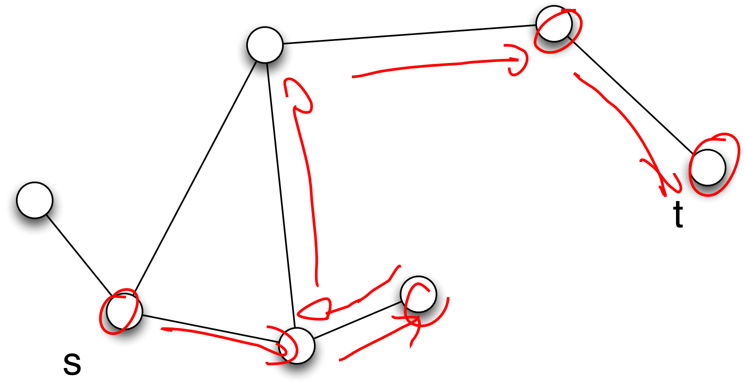
our Kuhn



Greedy forwarding and recovery

- **Right-hand rule needs planar topology**
  - otherwise endless recovery cycles can occur
- **Therefor the graph needs to be made planar**
  - erase crossing edges
- **Problem**
  - needs communication between nodes
  - must be done careful in order to prevent graph from becoming disconnected





Lower Bound

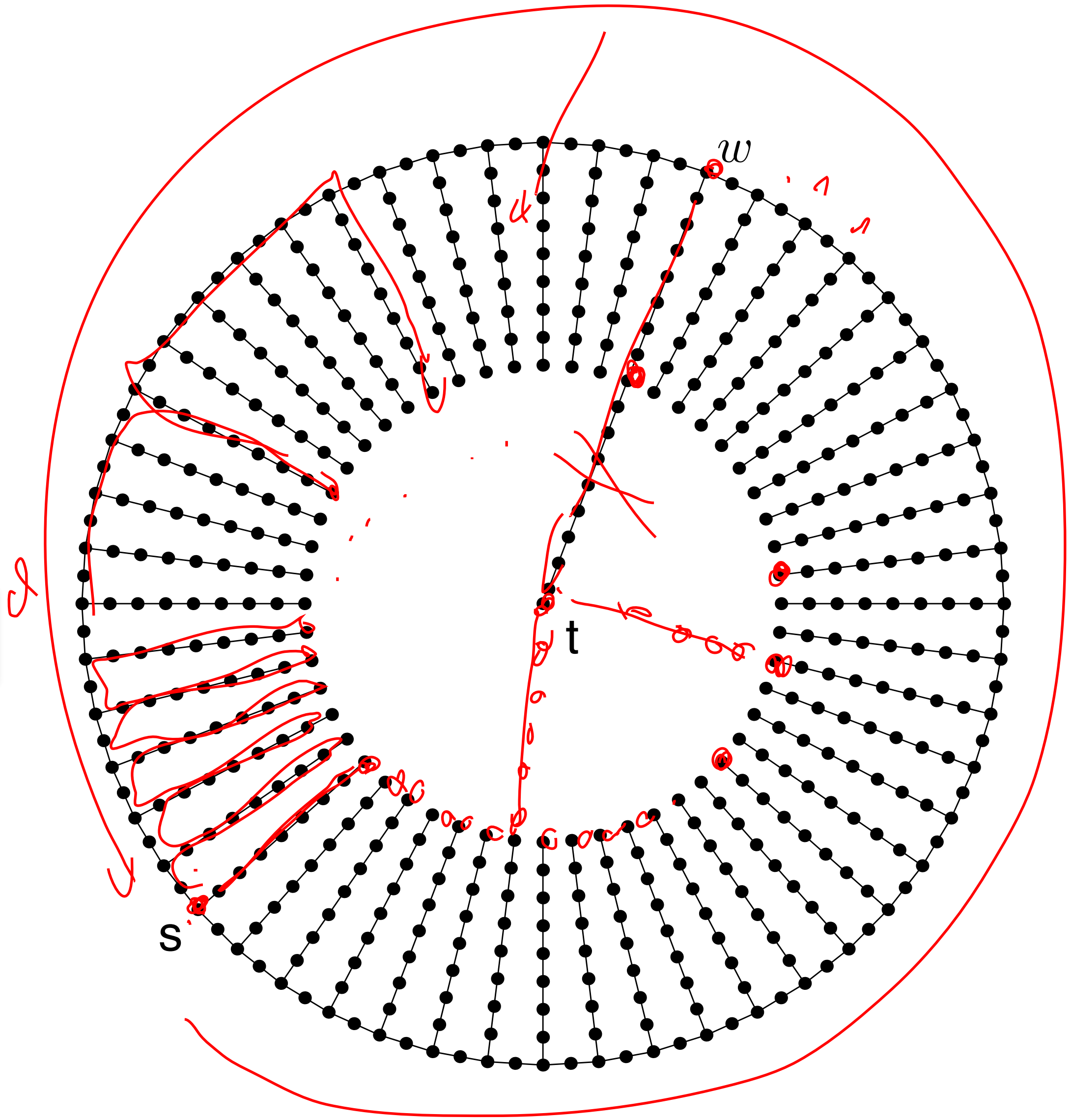
$\sim c \cdot d^2$

- **Kuhn, Wattenhover, Zollinger, Asymptotically Optimal Geometric Mobile Ad-Hoc Routing, DIAL-M 2002**

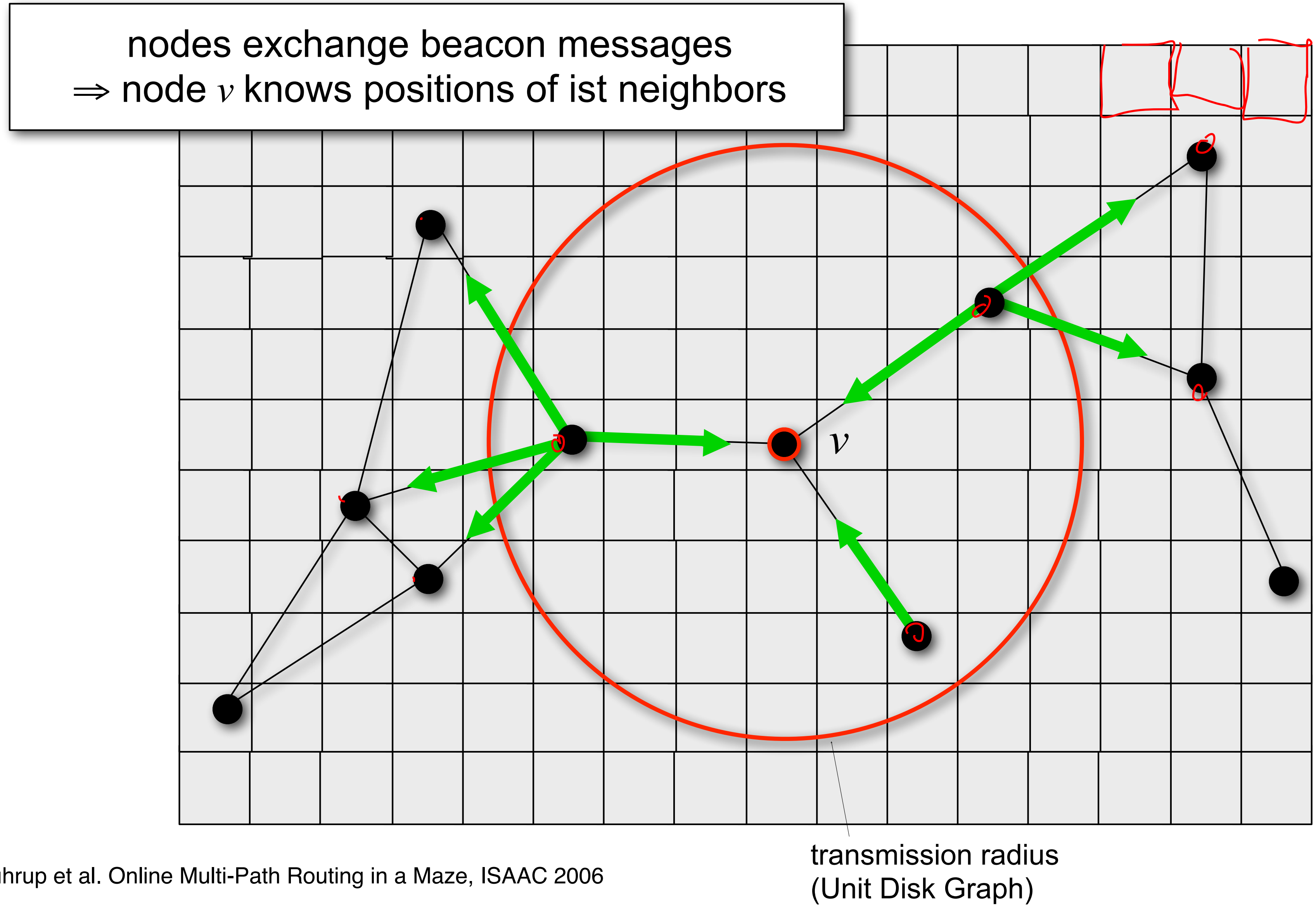
d = length of shortest path

time = #hops, traffic = #messages

Time: $\Omega(d^2)$

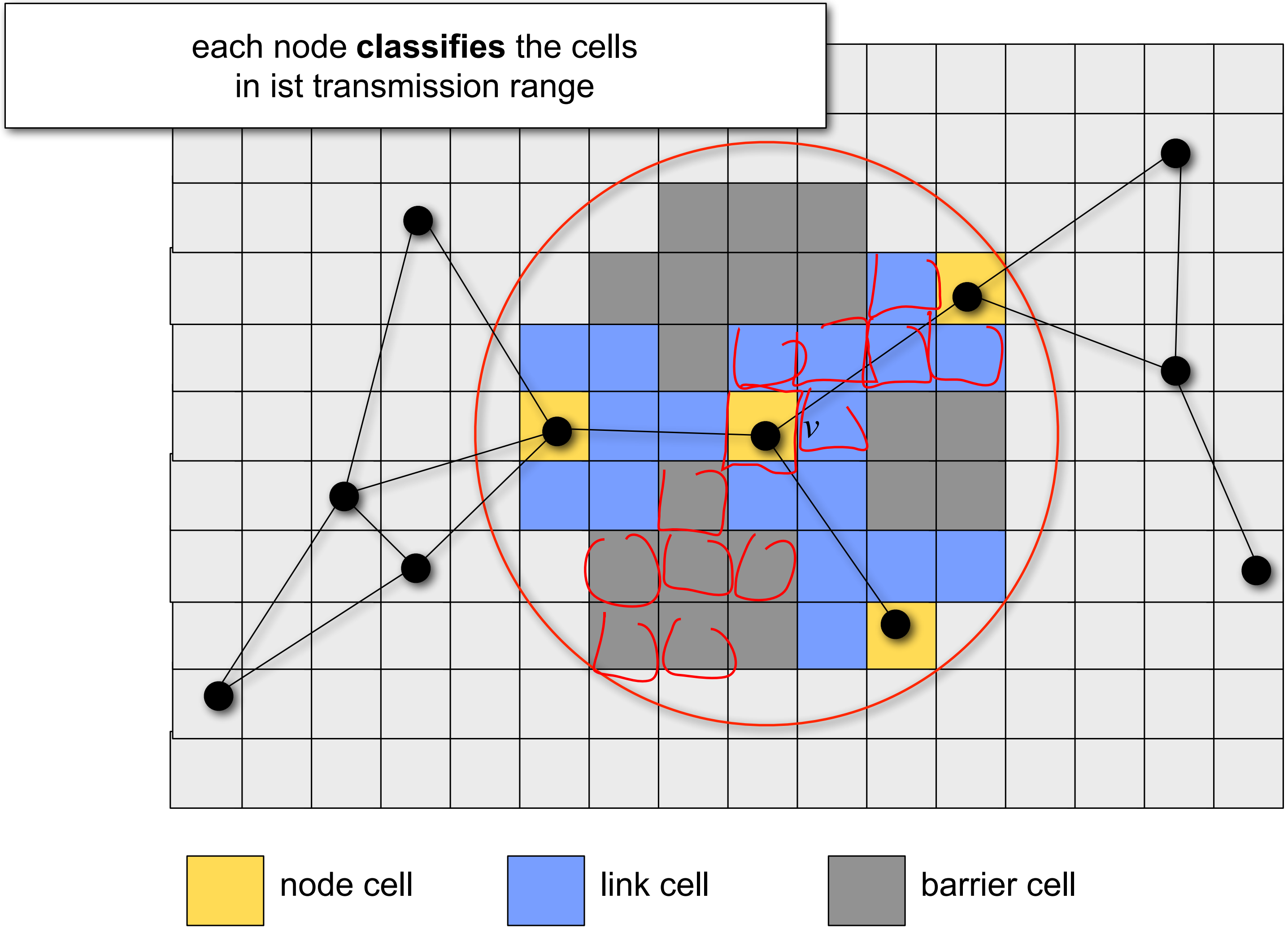


A Virtual Cell Structure



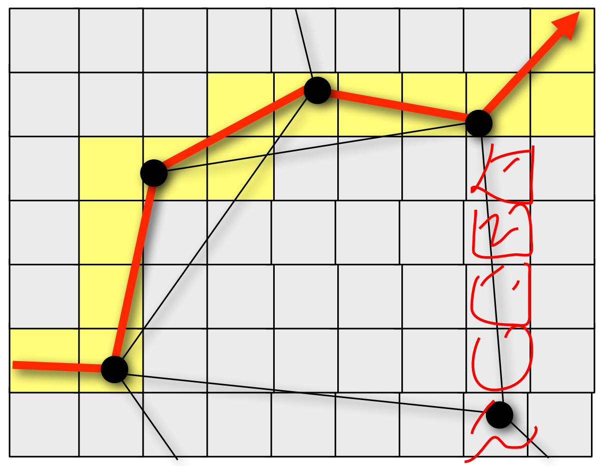
Rührup et al. Online Multi-Path Routing in a Maze, ISAAC 2006

A Virtual Cell Structure

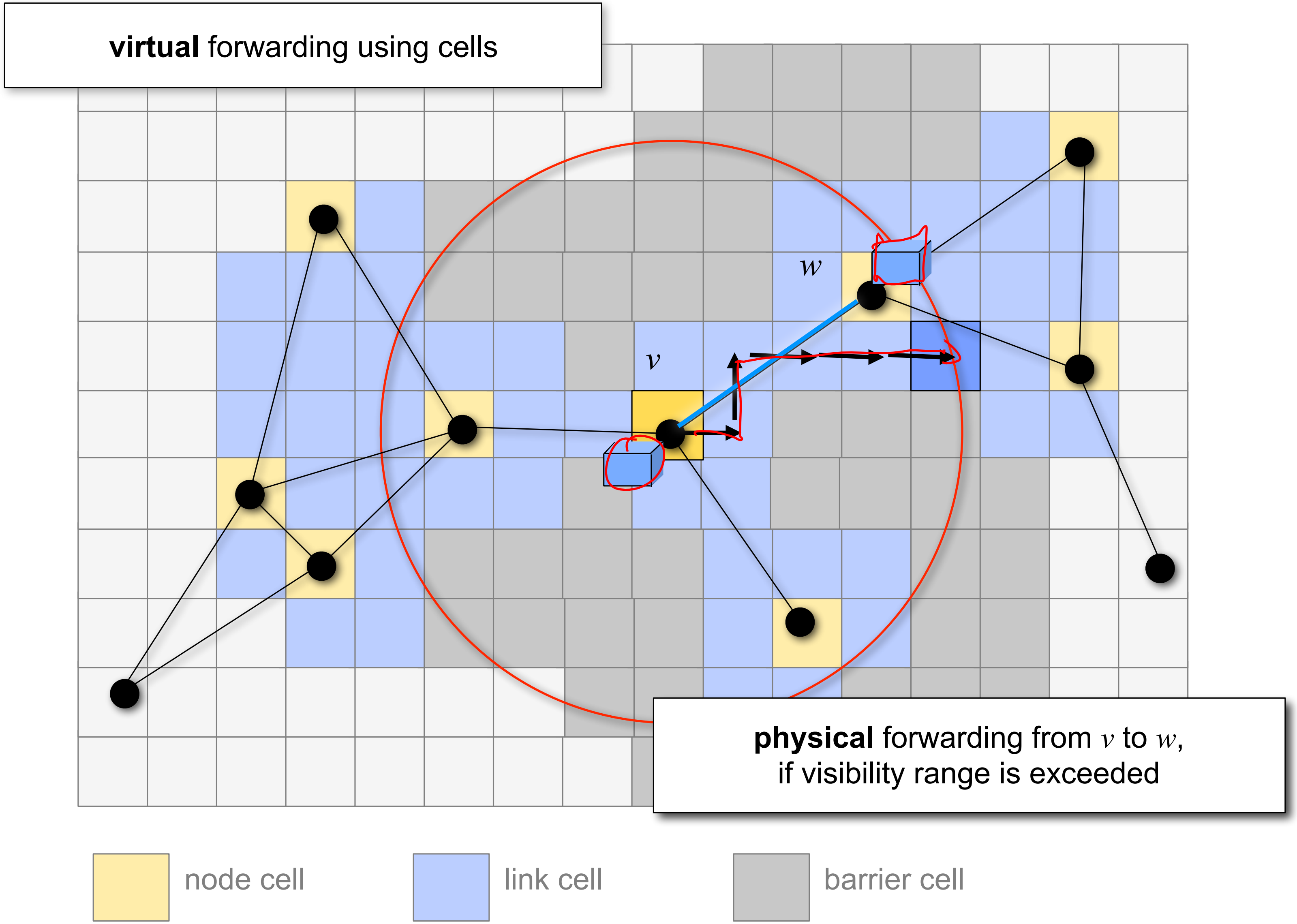


Routing based on the Cell Structure

- **Routing based on the cell structure uses cell paths**
  cell path
  - = sequence of orthogonally neighboring cells
- **Paths**
  - in the unit disk graph and cell paths are equivalent up to a constant factor
- **no planarization strategy needed**
  - required for recovery using the right-hand rule



Routing based on the Cell Structure



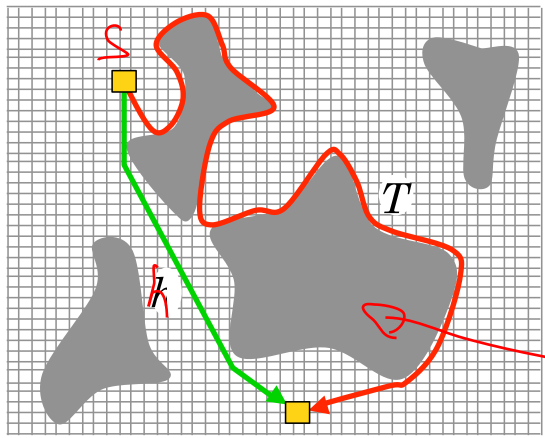
Performance Measures

- **competitive ratio:** $\dfrac{\text{solution of the algorithm}}{\text{optimal offline solution}}$

- **competitive time ratio of a routing algorithm**
  - h = length of shortest barrier-free path
  - algorithm needs T rounds to deliver a message

$$\mathcal{R}_t := \frac{T}{h}$$

single-path



grid

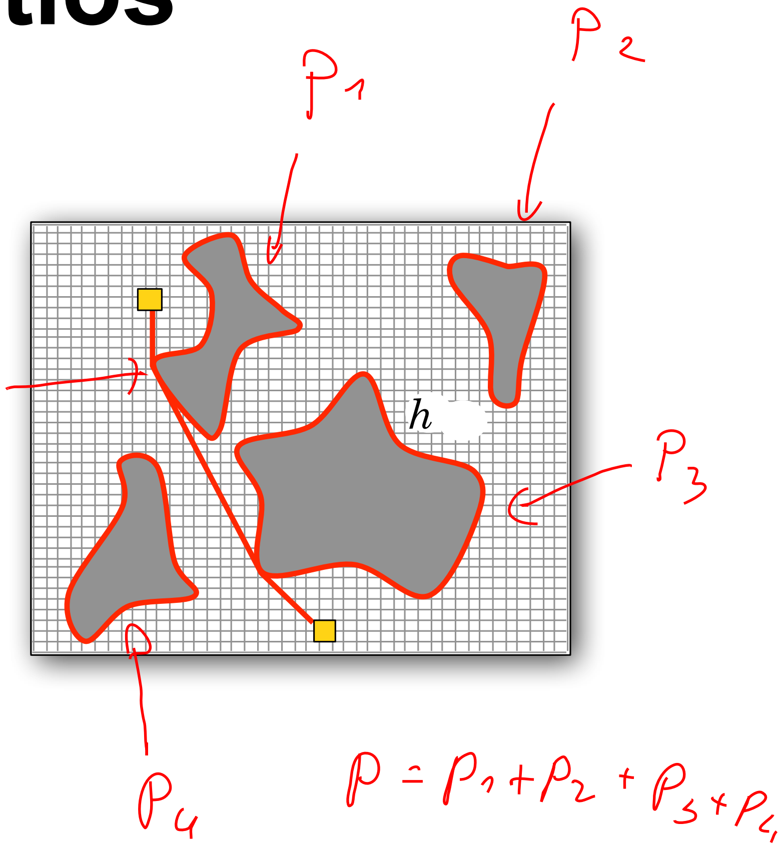
obstacles

Comparative Ratios

- **optimal (offline) solution for traffic:**
  - h messages (length of shortest path)
- **Unfair, because**
  - offline algorithm knows the barriers
  - but every online algorithm has to pay exploration costs
- **exploration costs**
  - sum of perimeters of all barriers (p)
- **comparative traffic ratio**

$$\mathcal{R}_{Tr} := \frac{M}{h+p}$$

M = # messages used
h = length of shortest path
p = sum of perimeters

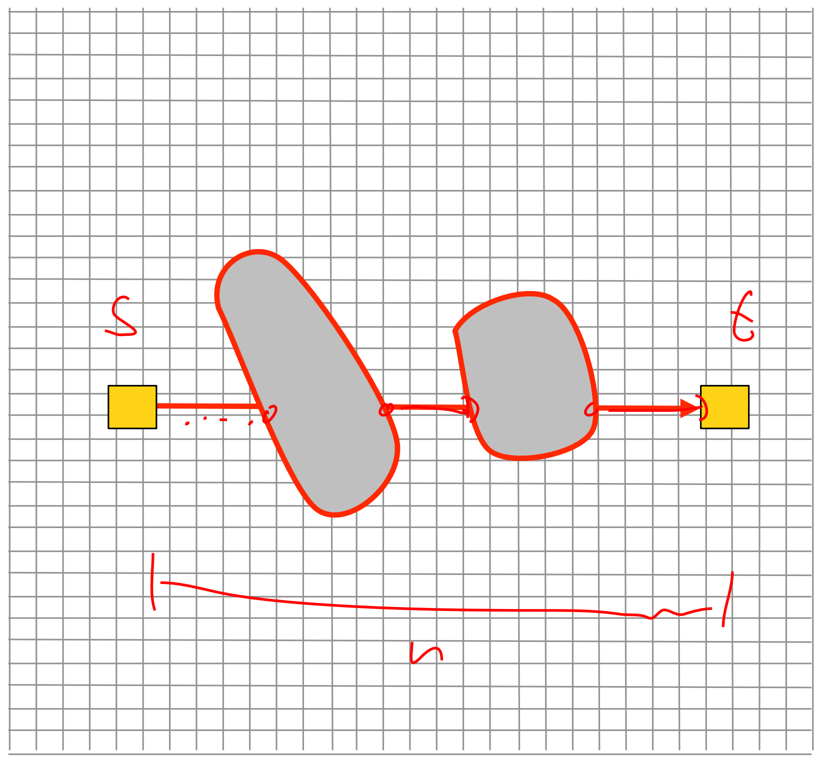


Comparative Ratios

- **measure for time efficiency:** $$\mathcal{R}_t := \frac{T}{h}$$
  - competitive time ratio
- **measure for traffic efficiency:** $$\mathcal{R}_{Tr} := \frac{M}{h+p}$$
  - comparative traffic ratio
- **Combined comparative ratio** $$\mathcal{R}_c := \max\{\mathcal{R}_t, \mathcal{R}_{Tr}\}$$
  - time efficiency and traffic efficiency

Single Path Strategy

- **no parallelism**
  - traffic-efficient (time = traffic)
  - example: GuideLine/Recovery
- **follow a guide line connecting source and target**
- **traverse all barriers intersecting the guide line**
- **Time and Traffic:** $\mathcal{O}(h+p)$



competitive time ratio: $\frac{h+p}{h} = 1 + \frac{p}{h}$

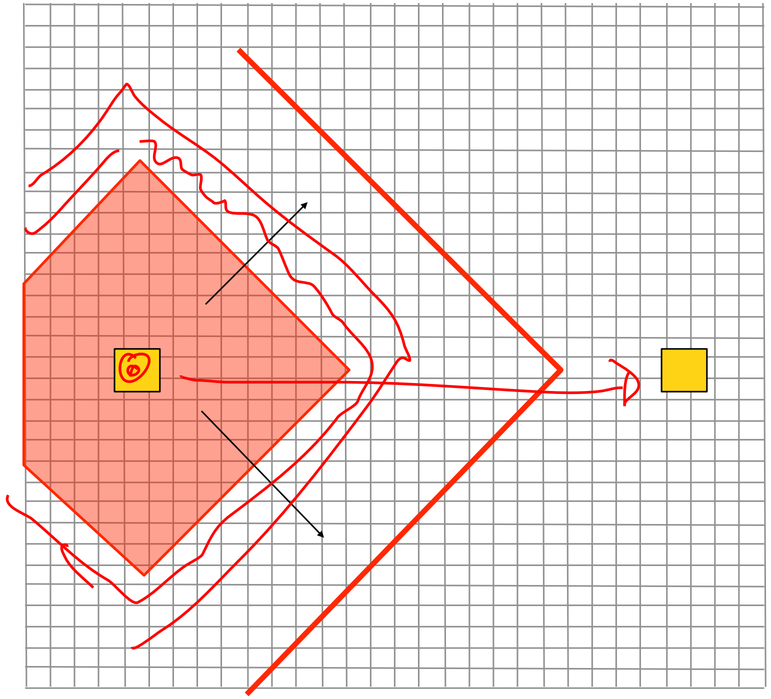
traffic ratio: $c\,\frac{h+p}{h+p} = O(1)$ time: $h+p$

Multi-path Strategy

$p = 0$

- **speed-up by parallel exploration**
  - increasing traffic
  - example: Expanding Ring Search
- **start flooding with restricted search depth**
- **if target is not in reach then**
  - repeat with double search depth
- **Time** $\mathcal{O}(h)$
- **Traffic** $\mathcal{O}(h^2)$

$$\frac{h}{h} = 1$$



traffic $\frac{h^2}{h+p} = \frac{h^2}{h} = h$ ~ 1

Algorithms under Comparative Measures

	time	traffic
GuideLine/Recovery (single-path)	$\mathcal{O}(h+p)$	
Expanding Ring Search (multi-path)	$\mathcal{O}(h)$	$\mathcal{O}(h^2)$

$$\mathcal{R}_t := \frac{T}{h}$$

$$\mathcal{R}_{Tr} := \frac{M}{h+p}$$

Is that good?

It depends ... on the	scenario	time ratio	traffic ratio	combined ratio
GuideLine/Recovery (single-path)	maze $p = h^2$	$\mathcal{O}(h)$	$\mathcal{O}(1)$	$\mathcal{O}(h)$
Expanding Ring Search (multi-path)	open space $p < h$	$\mathcal{O}(1)$	$\mathcal{O}(h)$	$\mathcal{O}(h)$

The Alternating Algorithm

- **uses a combination of both strategies:**

1. i = 1
2. d = 2^i
3. start GuideLine/Recovery with time-to-live = $d^{3/2}$
4. if the target is not reached then

   start Flooding with time-to-live = d
5. if the target is not reached then

   i = i+1

   goto line 2

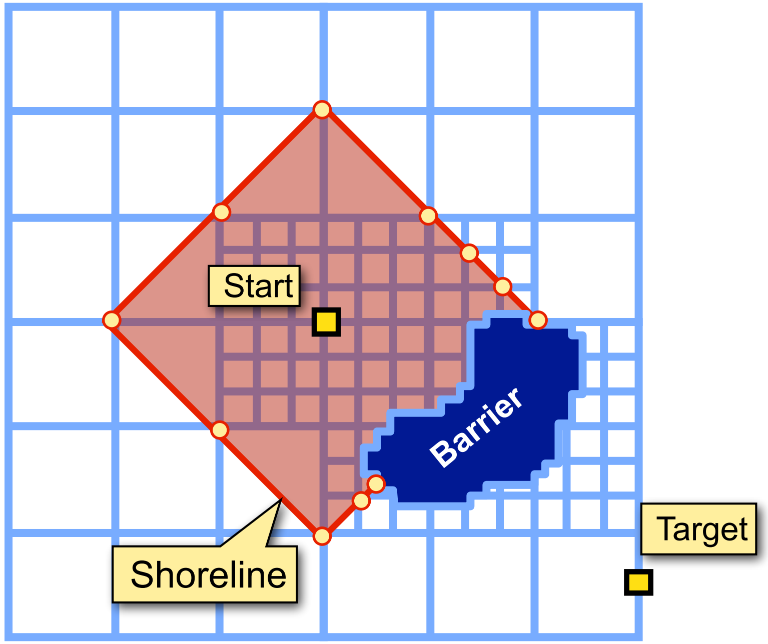
$\sqrt[3]{d^2}$

- **Combined comparative ratio:** $\mathcal{R}_c = \mathcal{O}(\sqrt{h})$

The JITE Algorithmus

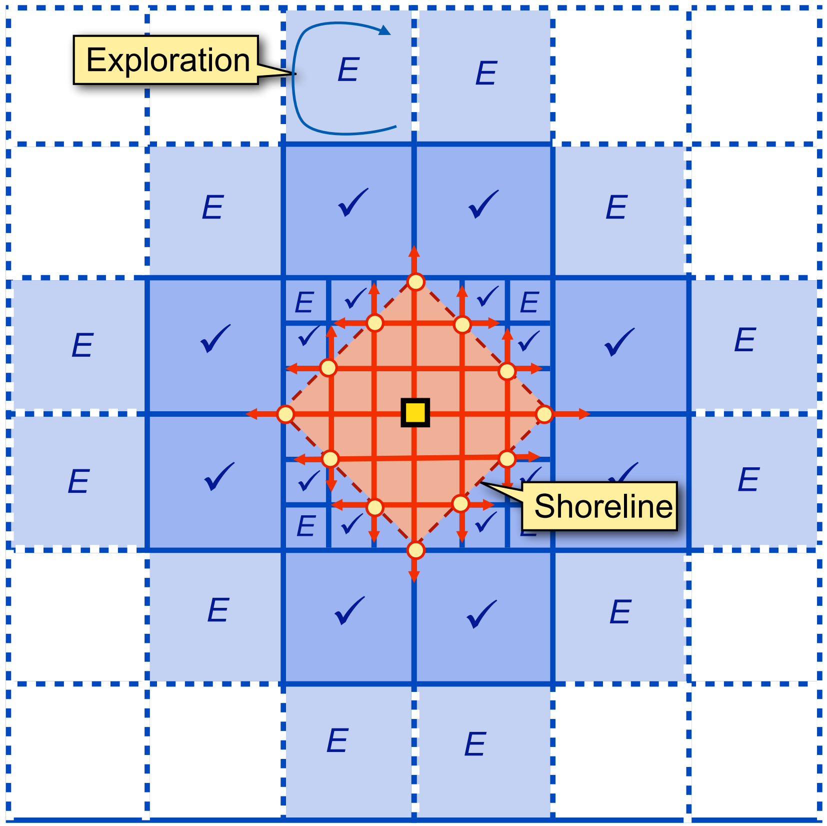
Rührup et al. Online Multi-Path Routing in a Maze, ISAAC 2006

- **Complex algorithm**
- **Message efficient parallel BFS (breadth first search)**
  - using Continuous Ring Search
- **Just-In-Time Exploration (JITE)**
  - construction of search path instead of flooding
- **Search paths surround barriers**
- **Slow Search**
  - slow BFS on a sparse grid
- **Fast Exploration**
  - Construction of the sparse grid near to the shoreline



Slow Search & Fast Exploration

- Slow Search visits only explored paths
- Fast Exploration is started in the vicinity of the BFS-shoreline
- Exploration must be terminated before a frame is reached by the BFS-shoreline



Performance of Geometric Routing Algorithms

Strategy	Time	Traffic	Comb. Comp. Ratio
Exp. Ring Search [9, 18]	$\mathcal{O}(d)$	$\mathcal{O}(d^2)$	$\mathcal{O}(d)$
Lucas' Algorithm [13]	$\mathcal{O}(d+p)$	$\mathcal{O}(d+p)$	$\mathcal{O}(d)$
Alternating Strategy [20]	$\mathcal{O}(d^{3/2})$	$\mathcal{O}(\min\{d^2, d^{3/2}+p\})$	$\mathcal{O}(\sqrt{d})$
Selective Flooding [21]	$d \cdot 2^{\mathcal{O}\left(\sqrt{\frac{\log d}{\log\log d}}\right)}$	$\mathcal{O}(d) + p\, d^{\mathcal{O}\left(\sqrt{\frac{\log\log d}{\log d}}\right)}$	$d^{\mathcal{O}\left(\sqrt{\frac{\log\log d}{\log d}}\right)}$
JITE (this paper)	$\boxed{\mathcal{O}(d)}$	$\boxed{\mathcal{O}((d+p)\log^2 d)}$	$\boxed{\mathcal{O}(\log^2 d)}$
Online Lower Bound (cf. [3])	$\Omega(d)$	$\Omega(d+p)$	$\Omega(1)$

Rührup et al. Online Multi-Path Routing in a Maze, ISAAC 2006

$\log^2 d \ll \sqrt{d}$

Summary

- **Geometric Routing**
  - is a scalable alternative with only local information
- **Recovery strategies**
  - are necessary since barriers might occur
- **Planarization**
  - underlying communication graph should be planar
  - erase edges or use cell structure
- **Performance**
  - should be measured by the competitive or comparative ratio
- **JITE**
  - best solution, but only of theoretical interest
- **Face Routing**
  - only of theoretical interest, because only a small fractions of the edges are used
- **Real-world Solutions**
  - Flooding
  - Alternating algorithm ?
  - Greedy with right-hand recovery
  - Greedy with flooding recovery

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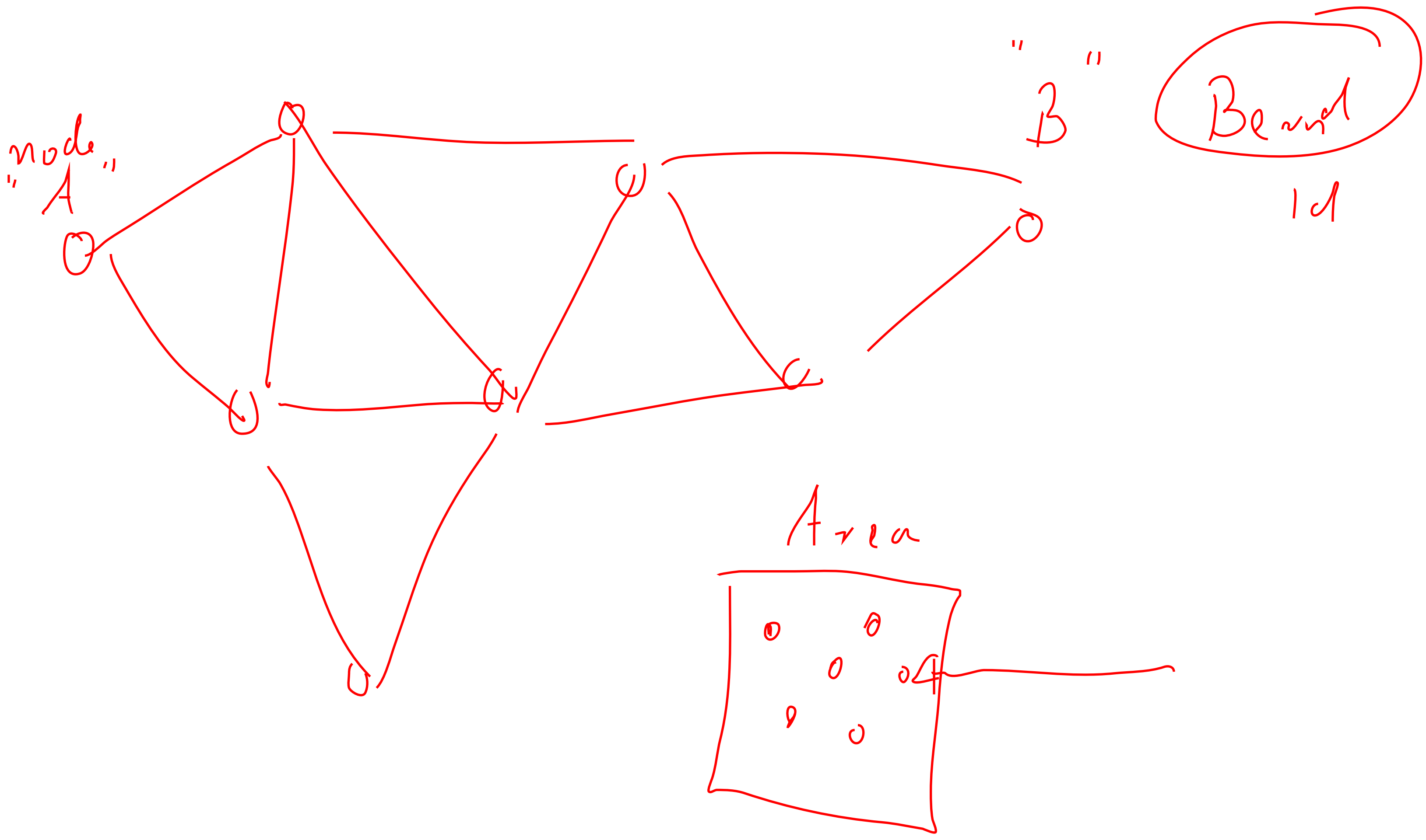
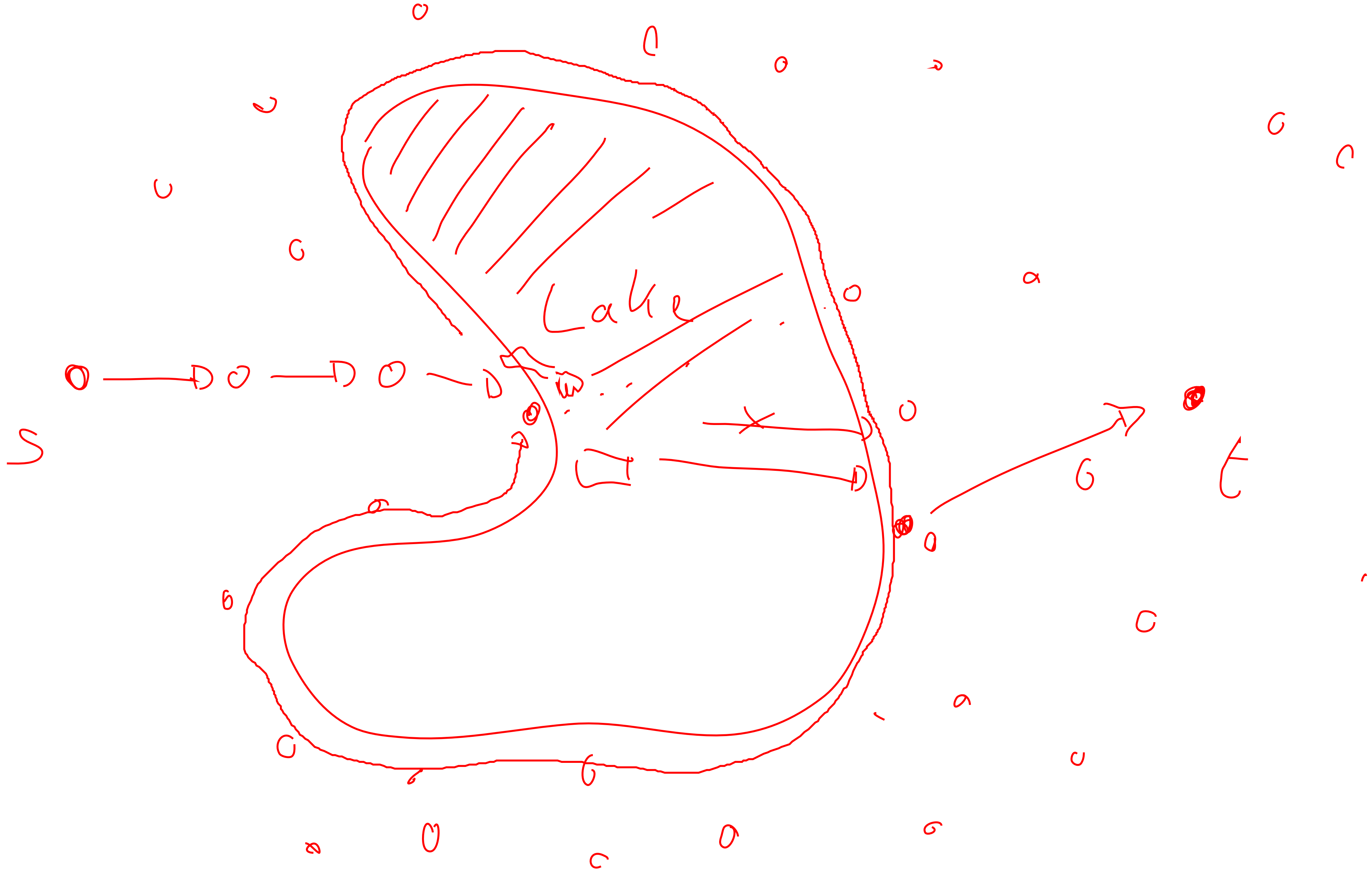
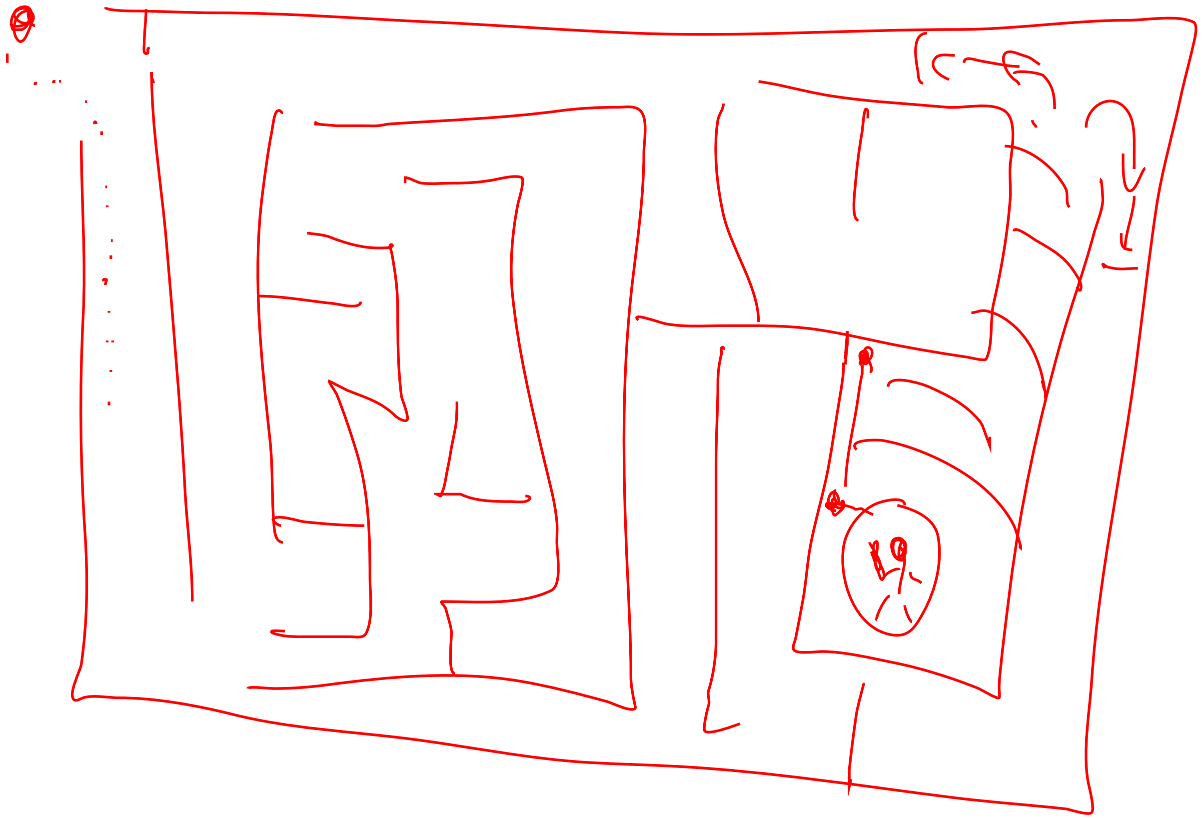

"node"
"A"
"B"
Bend
Id
Area



Lake
s
t

Maze



- Random Walk
- Right-hand rule

flooding ✓


s
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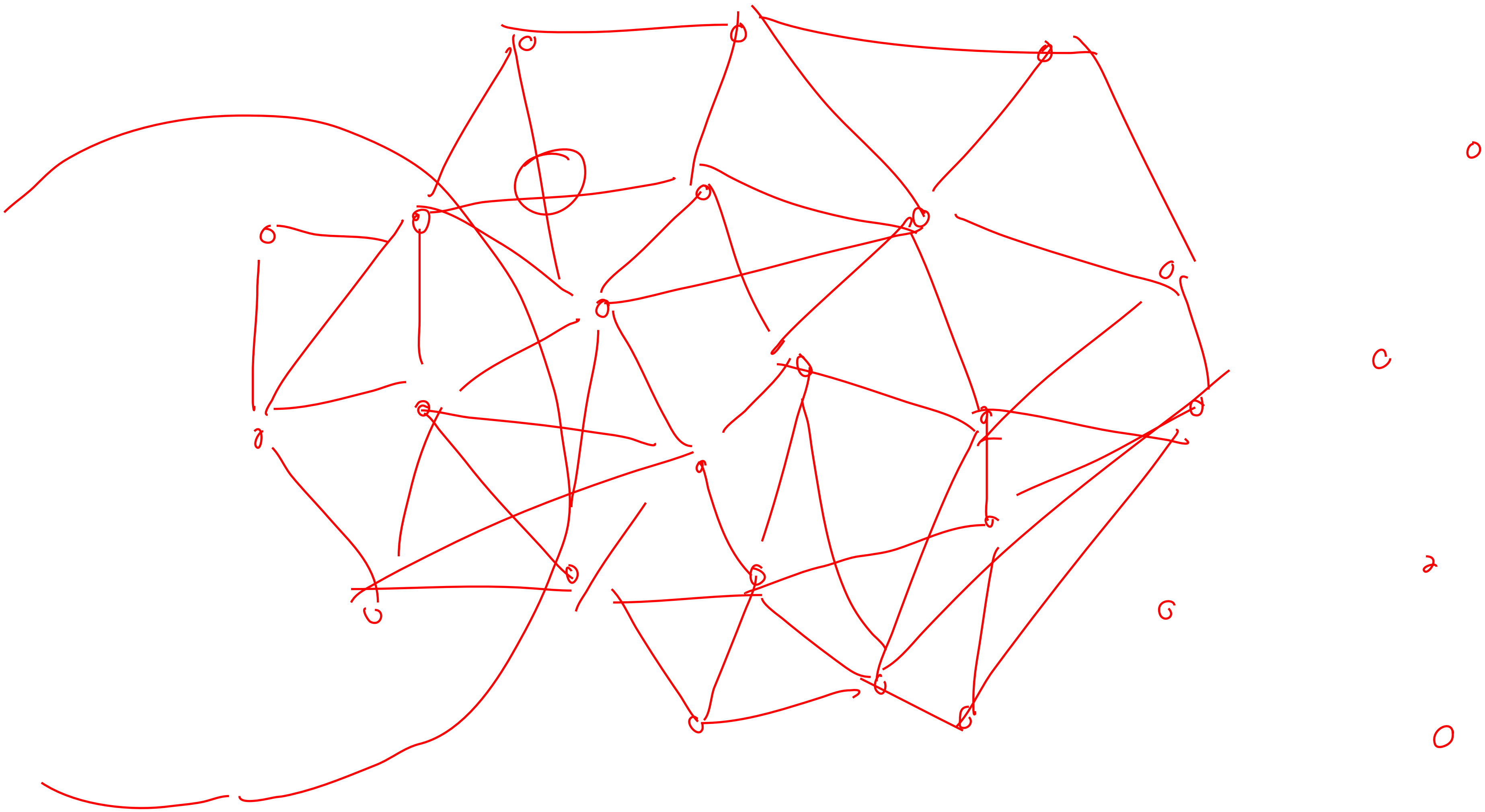

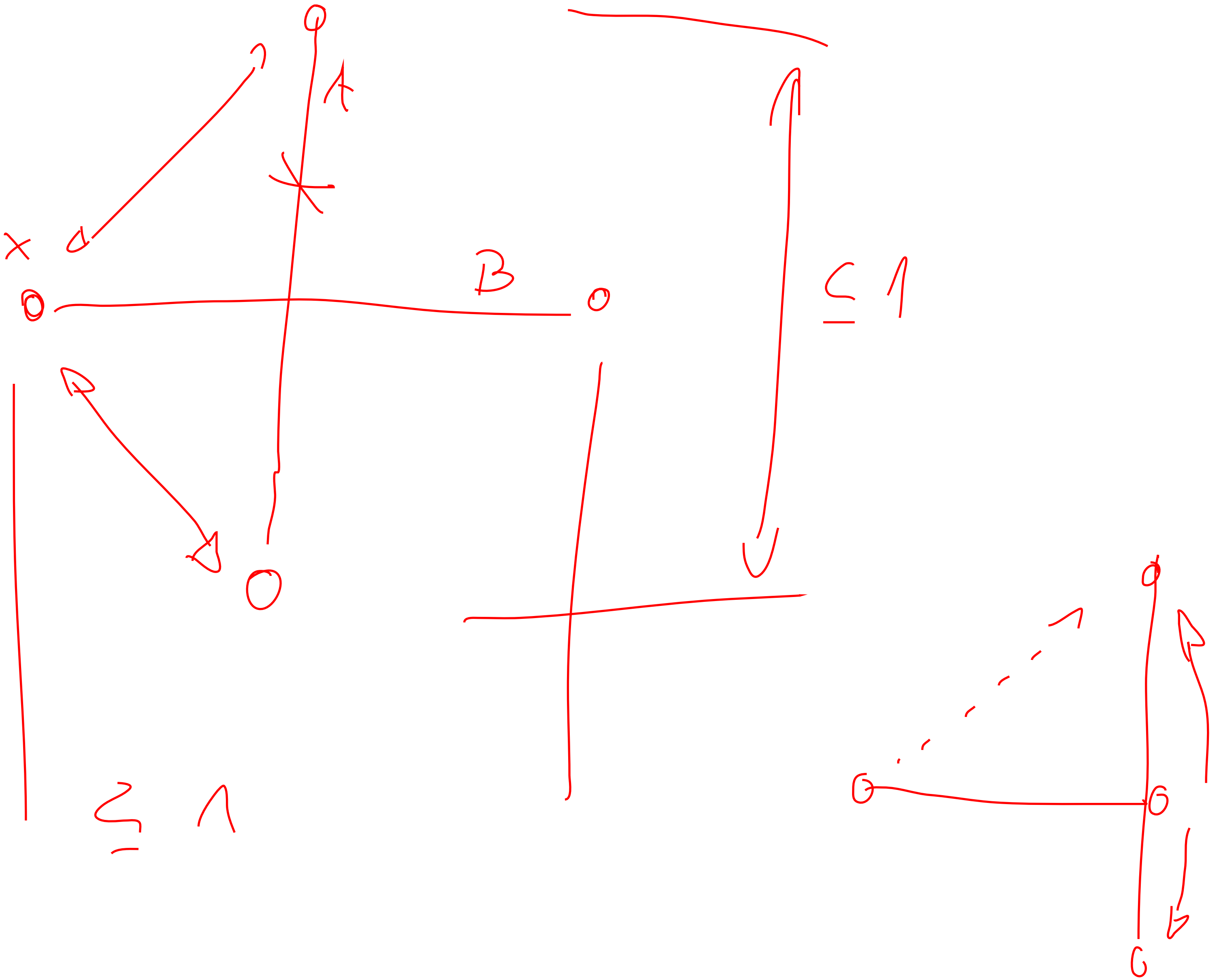
A
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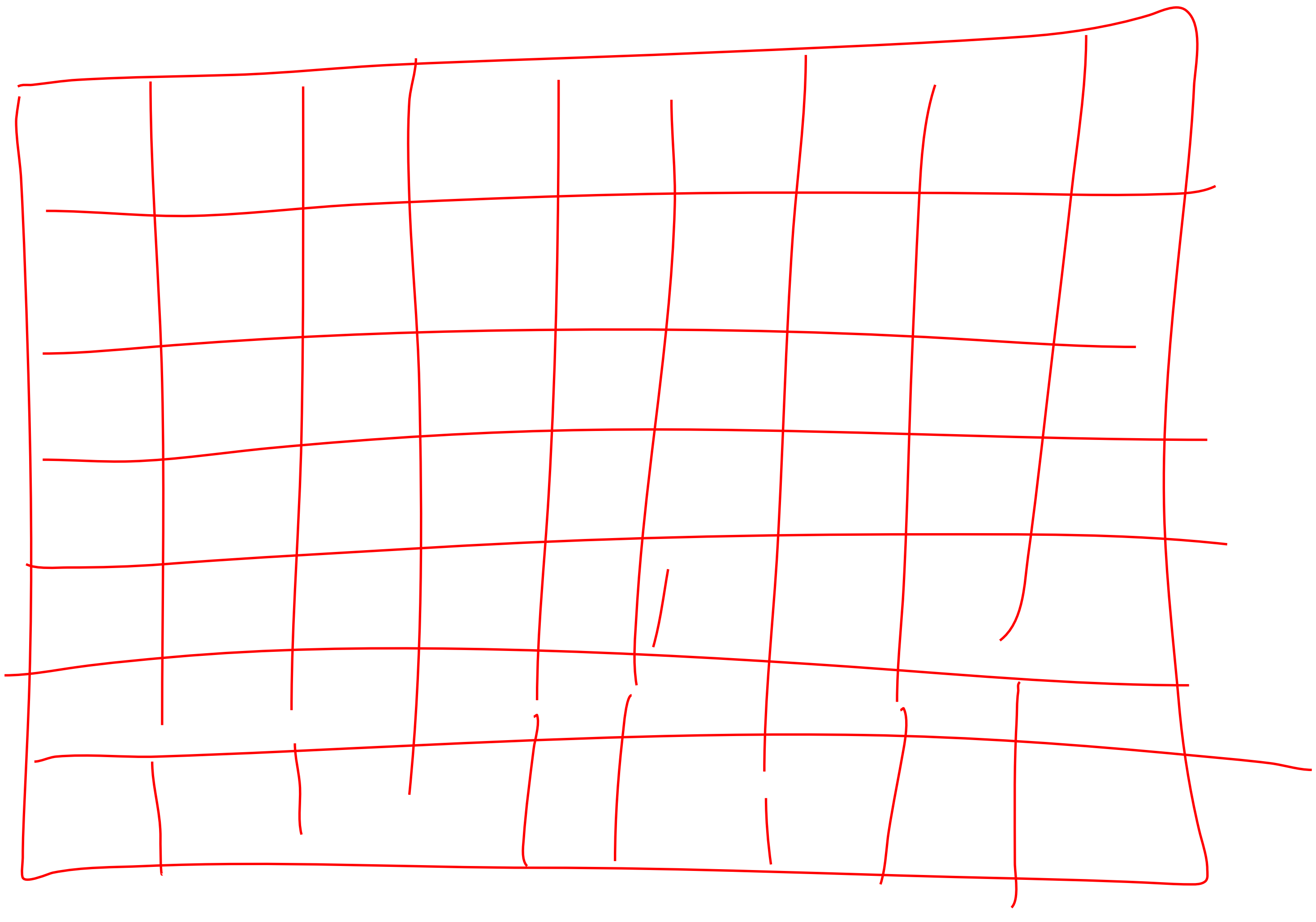
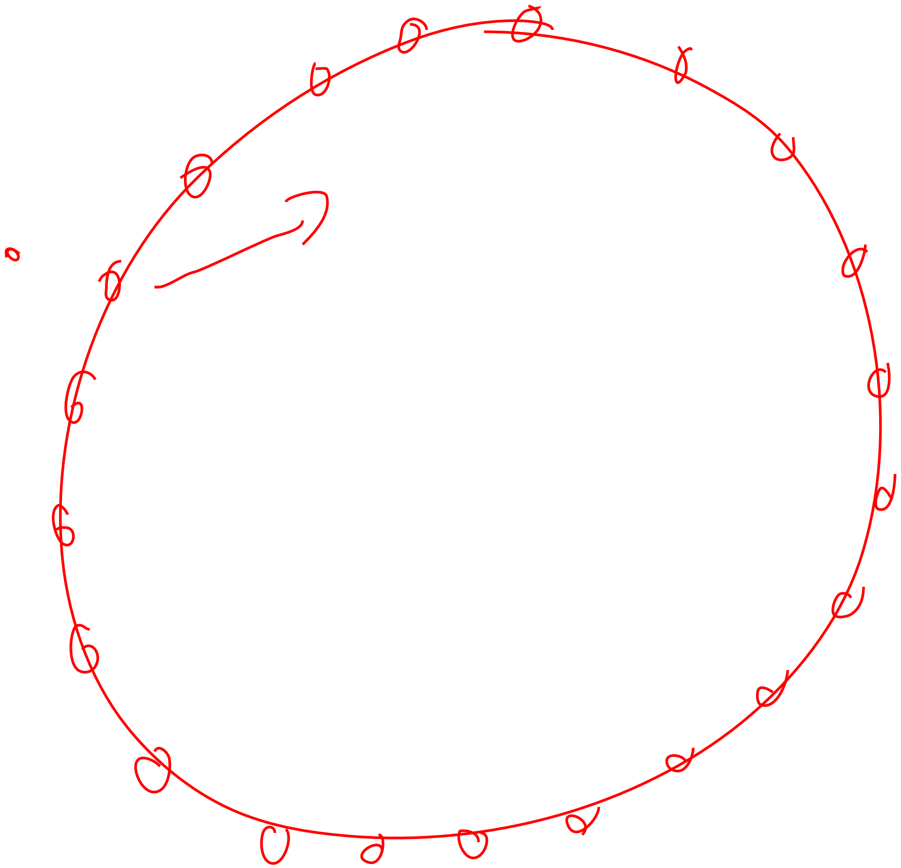
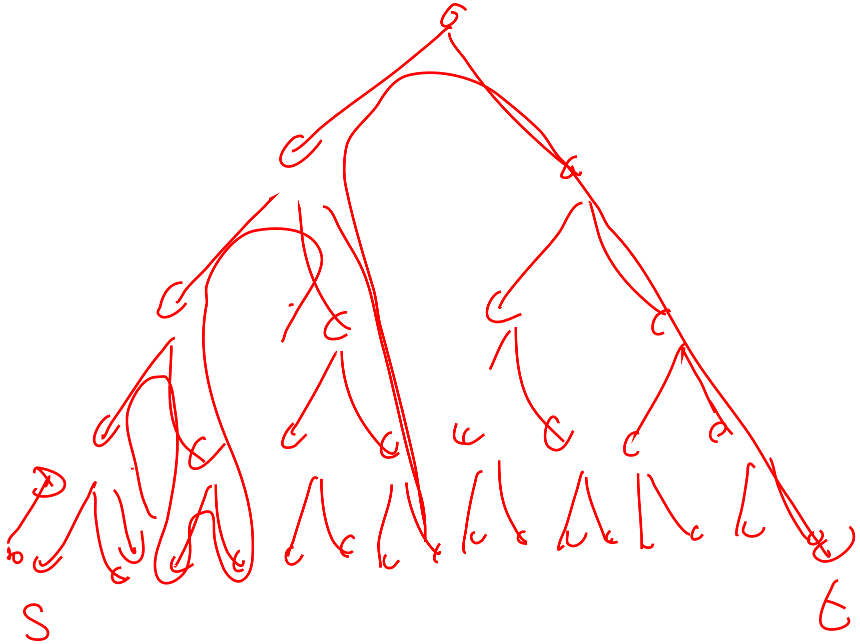
≤ 1
≤ 1



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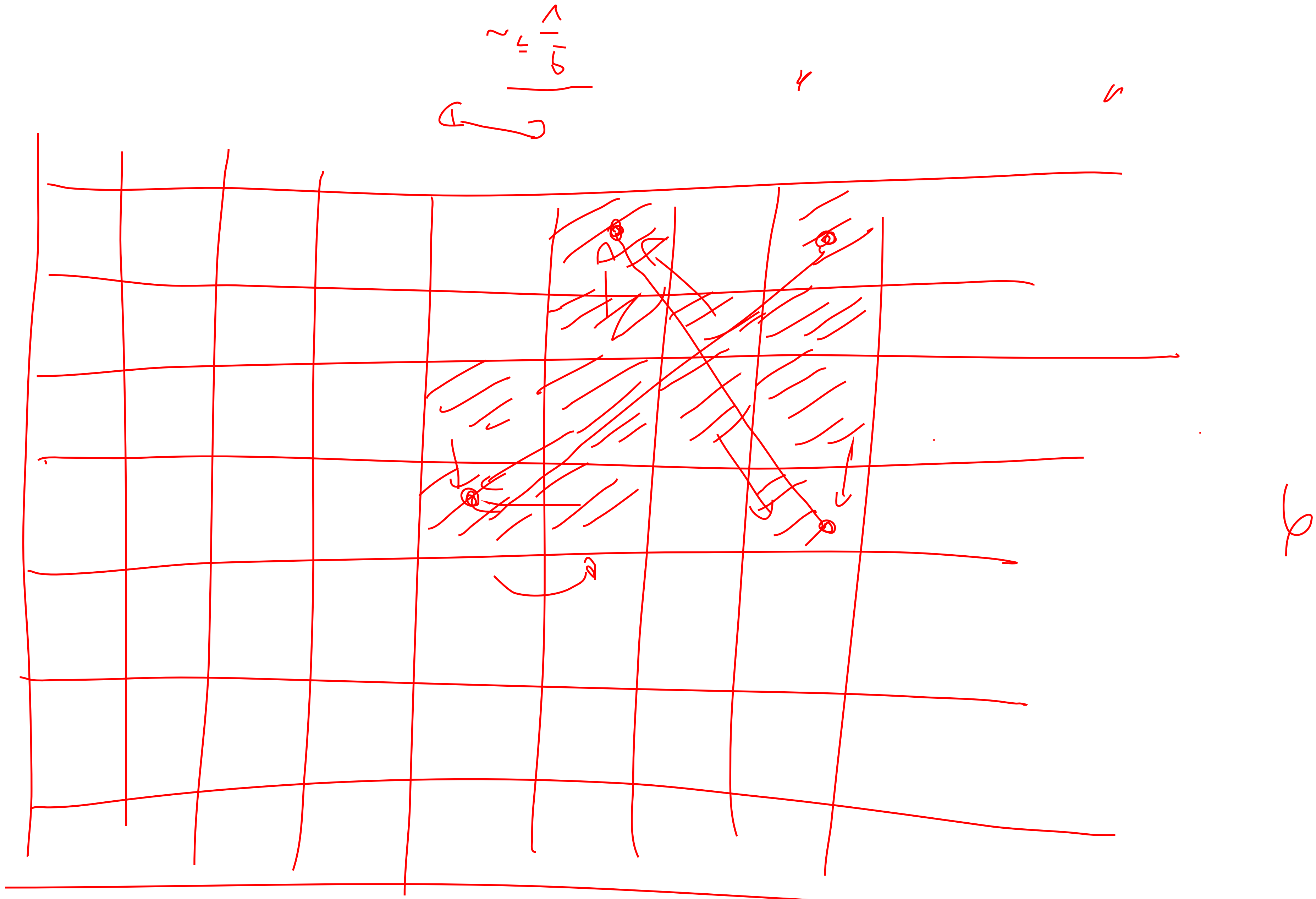
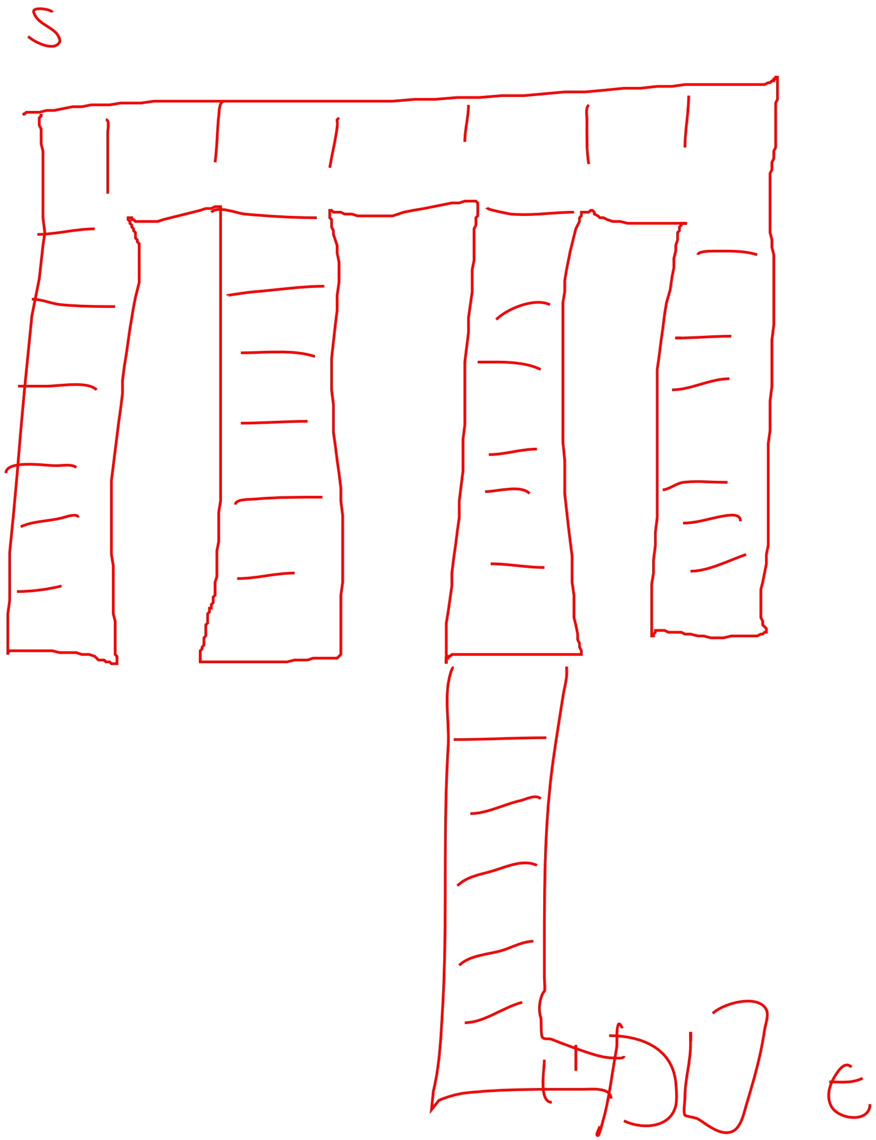
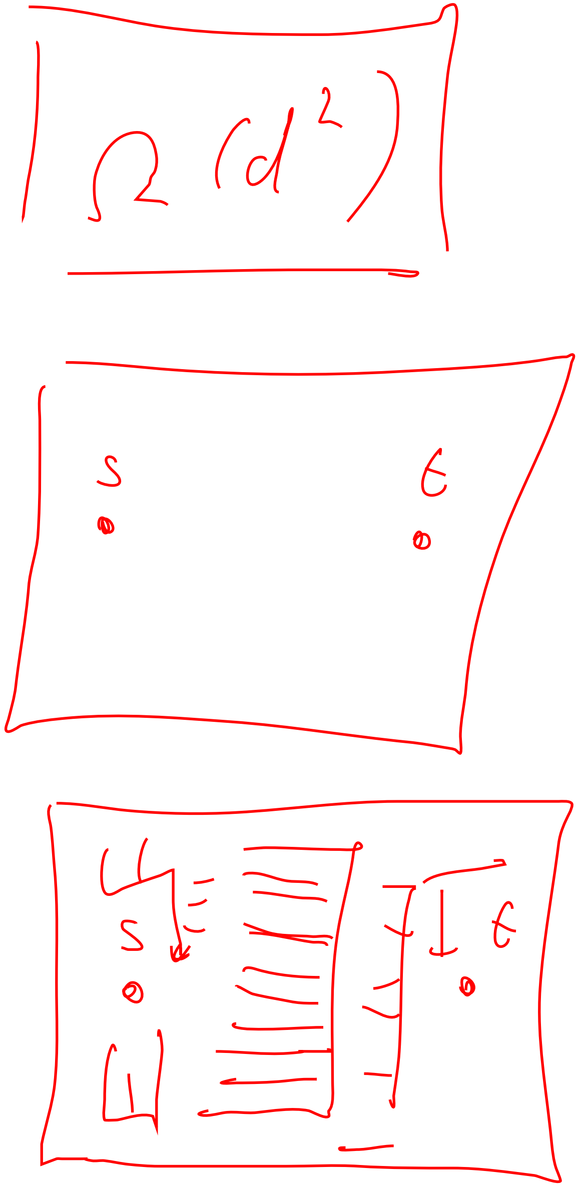






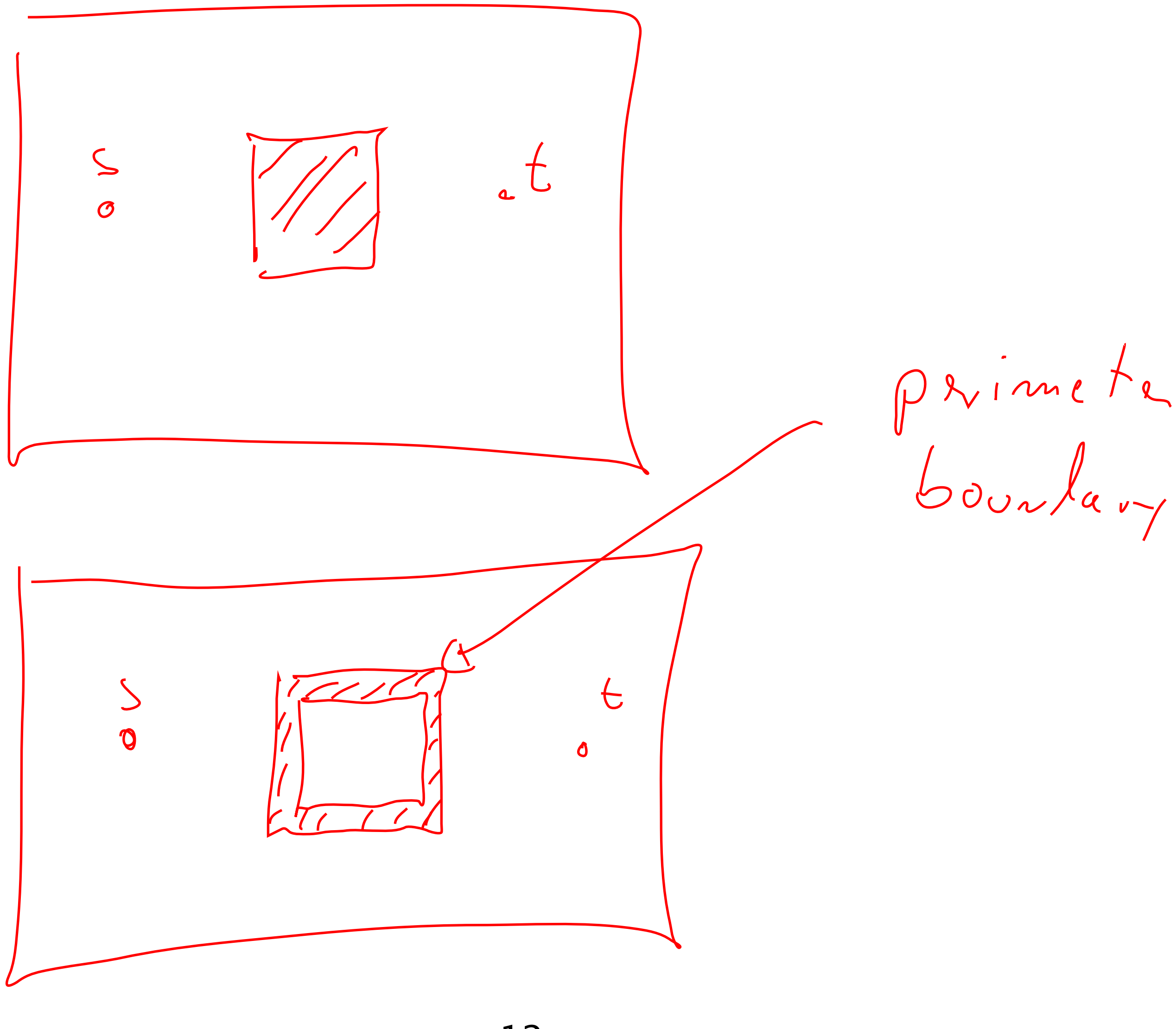
doesn't

easy

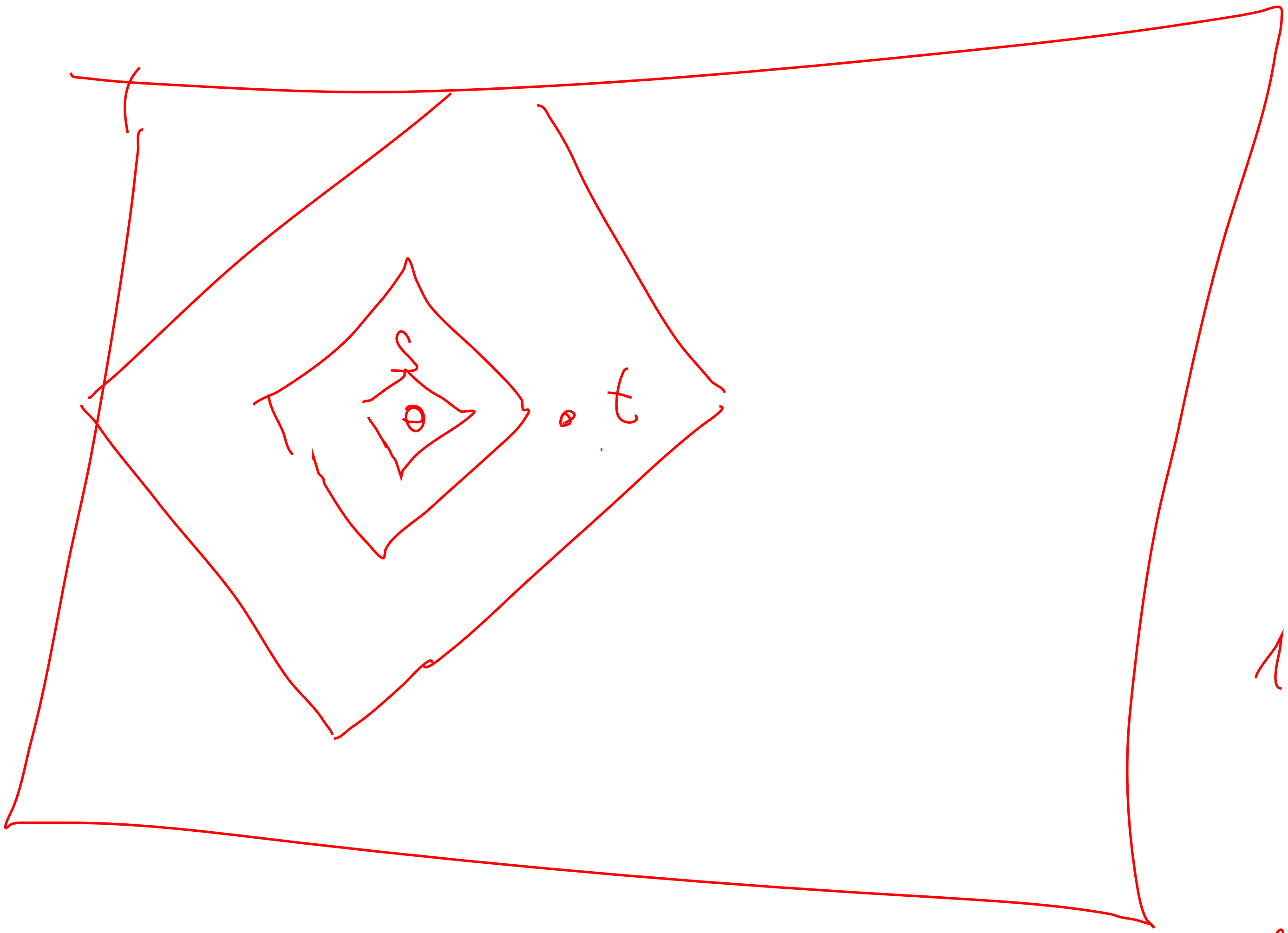
town

complicated

Dubai 1960



expanding ring search



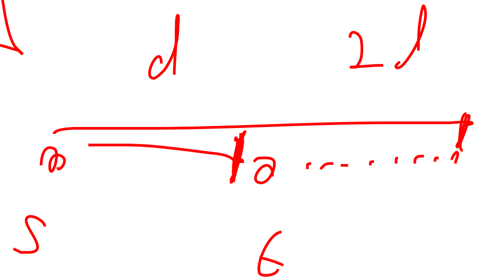
flooding with TTL 1

" " " 2

" " " 4

" " " 8

$$1 + 2 + 4 + 8 \ldots + 2^i = \underline{2^{i+1} - 1}$$



$$\frac{d^{3/2}}{d} = \sqrt{d}$$

$d^{3/2}$ $\quad$ d^2

$$\frac{d^2}{d^{3/2}} = \sqrt{d}$$

2